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Design and Fabrication of a Plastic Film Granulating Machine

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Abstract

Plastic film granulating machine is an industrial machine used for reducing plastic materials, mostly for grinding plastic into granules of uniform sizes for further processing either into new plastic shapes or recycled back to its parental source. This paper presents the use of locally sourced materials for realising the same machine; reducing its size and cost, while maintaining high efficiency, as well as decrease in vibration and increased shear efficiency with uniform size of granules. The machine consists of the hopper, the grinding chamber in which contains the shaft and cutting blades with a discharge unit. The plastic film granulator has a capacity of granulating 1kg of recycled plastic in 1h at 75% efficiency, a working revolution of 3000rpm, and power rating of 5.5hp engine. The machine works by principle of shearing, power is transferred from the motor to the granulating shaft with the aid of a transmission coupler that connects them. The inlet plastics are granulated until the desired size is achieved, small enough to pass through the discharge screen.

1. Introduction

Plastic recycling or recovery is an effective way and approach to conserving resources and also cost reduction mechanism; hence, the desire to construct a plastic film granulating machine is imperative (Milgrom, 1982). Plastics are typically polymers charge molecules that are composed of repeating structural unit typically connected by covalent chemical bonds of high molecular mass and their wider or diversified applications have assisted the plastic industries to achieve remarkable success in the modern global market (McRandle, 2004).

Granules are agglomerates or form of pellets, which consists of primary particles that are extensively utilised in different industries. There are several techniques for the production of granules available for engineering and pharmaceutical purposes (Ghebre-Sellasie *et al.*, 2001). The wet granulation approach utilises binder solutions or solvents to agglomerate powders. These methodologies include the fluid bed granulation, high shear granulation or the spray drying processes (Keleb *et al.*, 2002; Schroeder & Steffens, 2002). Conversely, the dry granulation methods, use mechanical pressure for agglomeration, e.g. slugging and roller compaction. Metallic substances enable particle size enlargement for dry granulation processes, which can be performed in high shear mixers (Selkirk & Ganderton, 1970). The powder particles in these processes are enlarged up to granules with a particle size range from 0.1 to 2.0mm or palletised in the presence of binder using palletising machine.

The advent of plastic recycling and higher demand for plastic product, gave birth to the invention of plastic granulating machine. There are different types of granulating machine in terms of constructional features but their working principle are the same (Khurmi & Gupta, 2007). Their drive systems are mostly belt-pulling systems, which are driven by an electric motor. The size of the electric motor depends on the size of the machine and then required output product.

A granulator is a high speed typically open rotor knife mill, designed to take a large component of feed stock (such as plastic bottles) and reduced them to at least a particular size of approximately 40 mesh to 1/8

chip. And why many granulators are utilised for processing material output of greater than 1/8, its still remains that their primary pace is in the reduction to the finer grains (Jordan Reduction Solution, 2015).

Why that may be an overall simplistic definition it does compromise the most common usage of equipment and it should be noted that other styles do exist, such as closed rotor design, higher production models and really a multitude of similarly designed rotors, however even with these options, which are often to facilitate different feed stocks, the output of a granulator still remains close to the same sizing.

Plastic granulators are one of the first, and still most commonly used, machines for reducing the size of plastic waste prior to recycling. The particle size output by a granulator is determined by the size of the holes in the granulator's output screen. If materials that are too large, have too much mass, or have a critical combination of these two factors enter the cutting chamber, damage is inevitable. Moreover, the speed at which the rotors spin, combined with the surface area of the "open rotors" results not only in damage, but sheared metals parts travelling at high rates of speed within the machine. Because of these restrictions, scrap material often has to go through some form of size reduction prior to being introduced to the granulator. Vecoplan (2014) offers a stack system for these applications. Shredders can handle scrap of virtually any size or shape. A stack system incorporates a shredder for initial sizing of material working with a granulator for final size reduction. The granulator is mounted beneath the shredder. Large scrap is reduced to the appropriate size by the shredder, and then fed directly into the granulator for final sizing. Vecoplan stack system is adept at applications that require the processing of very large volumes of material to very small particle sizes and at high feed & output rates (Vecoplan, 2014).

In general, plastic recovery has become a positive step in arresting the situation of littering our surroundings with plastic waste, thereby in a way maximizing the productivity of plastic product, this is achieved by the industrial recycling of plastic waste through the use of simple recycling machine and granulators (Henson, 1998).

2.   Methodology

2.1   Material Selection

A detailed consideration of the design requirement is made with respect to homogeneity in relationship between parameters and properties. Due to cost consideration and tendency for failure to occur during service or granulation: material selection is made an integral part of the design process and should enumerate for instance the following:

 (a) strength of material (such as ultimate tensile stress, modulus of elasticity etc.);
 (b) mechanical tendency of the materials;
 (c) thermal and chemical properties of the material;
 (d) cost and availability of the materials; and
 (e) ease of fabrication of the materials (e.g. availability and machinability etc.).

The materials used for the plastic granulator are 3mm sheet metal, 2 inches angle bar, 5.5hp engine, 12mm bolt and nut, four 13mm bolts, eight 17mm bolt and nuts, car paint, stainless steel, net of 6mm hole, and Stainless steel 3 inches pipe.

2.2   Major Machine Component Description

Before the design of the plastic film granulating machine, the design of the following component will be looked into. The component are cutting blade, power transmitter, hopper and shaft, shock absorbing coupler, discharge unit, and bed. In order to design the components stated, there is need to have some design parameters according to experimental information collected from previous works based not almost on this particular model. The parameters include:

 (a) *The Capacity of the Blade:* The plastic film granulating to be designed is expected to have a capacity of granulating 1kg of waste plastic in one hour.

 (b) *Rotational Speed of the Blade:* For effecting cutting, the blade needs to rotate at a very high speed in the neighbour-hood of around 2000–3000rpm. For the purpose of this design a speed of 2000rpm will be desirable.

 (c) *Minimum Pressure to Granulate:* The minimum pressure expected to granulate recycled plastic ranged from 20-30psi depending on the toughness of the plastic of which thermosets are harder as compared to other polymers depending on the toughness. For the purpose of this project a plastic requiring 23psi pressure to granulate the plastic will be assumed.

 (d) *Design of the Hopper:* The hopper design is governed by the capacity of the granulator. The granulator capacity is 1kg per hour as stipulated earlier which 1 kilogram of waste plastic would be sliced in a minute. Also to

allow for early and controlled introduction of the waste plastic in the grinding chamber, the hopper will take the shape of a frustum of a pyramid. The density of the granulated polymer is deduced as follows:

$$Density = \frac{mass\ (g)}{volume\ (v)} \tag{1}$$

$$Density = \frac{1000g}{50\ cm^3} = 20\ g/cm^3$$

The hopper has a square base of bottom 30cm x 30cm. Hence, the volume of hopper is deduced as:

$$V = \frac{1}{3} \times A \times H - \frac{1}{3} \times a \times H \tag{2}$$

Where, H is the Height of required hopper, A is the area of the top of hopper, a is the area of the bottom of hopper and V is the volume of the hopper. Therefore:

$$V = \frac{1}{3} \times H(A - a) \tag{3}$$

Where $A = L \times B = 41 \times 41 = 1681cm^2$, a = l x b = 30 x 30 = 900cm², H = 67cm, thus:

$$V = \frac{1}{3} \times 67(1681 - 900)$$
$$V = \frac{67}{3}(781)$$
$$V = 22.33(781)$$
$$V = 17439.73\ cm^3$$

If 20% is allowed for the wasted space due to standing in the hopper therefore the volume of the hopper will be:

$$V = \frac{Calculated\ volume}{\%\ being\ utilized} \tag{4}$$

$$\%\ being\ utilised = 80\% = \frac{80}{100} = 0.8$$
$$V = \frac{17,439.73}{0.8}$$
$$V = 21,799.663\ cm^3$$

2.3 Design of the Blade

The design cutting pressure ranges from 20-30psi of a mild steel plate of 3mm thickness or a stainless steel plate is used but preferable stainless steel due to its strength and ability to withstand corrosion and utmost due to the fact that it doesn't get blunt easily. If a stainless steel plate of 3mm is going to be used and considering the length to be 3cm. the area would therefore be:

$$A = L \times B \tag{5}$$

Where A is the area of the blade, L (= 3cm) is the length of the blade, and B (= 3cm) is the breath of the blade. Also, 20psi = 137,895pa = 138KN/m²; 30psi = 206,843pa = 207 KN/m². For the purpose of this design, since 23psi =15879pa=15.9KN/m² was used, then (5) reduces to: A = 9 x 10⁻⁴m²

Let P (= 15.9x10³) be the pressure developed in the blade, then the horizontal force, F is deduced as:

$$F = Pressure \times Area \tag{6}$$

F = 15.9x10³ x 9x10⁻⁴
F = 14.31N

Therefore the blade force is 14.31N. Since the plastic is going to drop under gravity, there is no need to consider the weight, $W = Mg$, where W is the weight of the recycled plastic, M is the mass of the recycled plastic, and g is the acceleration due to gravity (10m/s²). Hence,

W = 1000/1000 x 10 = 10N \tag{7}

The weight (the vertical force) the vector diagram at point of striking is dissipated as shown in Figure 1.
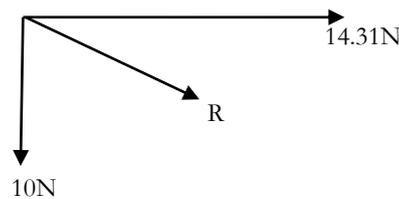
Figure 1. Diagram representing the vertical point at point of striking

Resolving the forces

$R = \sqrt{(14.31)^2 + (10)^2}$

$R = \sqrt{304.7761}$

$R = 17.5N$

Since the blade is rotating, its force

$F = Mr\omega^2$ (8)

For a case where, F (= 2.539N) is the resultant force, M (= 50g) is the mass of the blade and r is the actual length of the blade being the radius of the circular motion deduced as follows:

$r = \frac{F}{M\omega^2}$ (9)

Assuming the rotational speed of 3600rpm (=60 rev per seconds), then:

$\omega = 2\pi N$ (10)

$= 2 \times 3.142 \times 60$

$= 377 rad/sec$

$r = \frac{17.46 * 1000}{50 * 377^2}$

$r = 0.0025m = 2.5mm$

Therefore actual length of the blade being the radius of the circular motion is 2.5mm or 2.5×10^{-3}m

2.4 Design of Shaft

Power transmission shaft is a solid responsible for transmission of power from the source to where power is required. Generally rotating shaft are circular in cross section. Shaft are loaded in various ways such as tension, bending, oval and transverse load. Shaft are subjected to combined fluctuations load which ultimately lead to fatigue failure if not properly designed. Some of the factors considered in shaft design are stress concentration, deletion due to vibration, the material used and cross sectional profile of it. It is equally advisable to hold deflection as shaft to known limit which is very low.

For the purpose of this project the shaft is located close to the supporting bearing to reduce bending moment deflection and bending stress. In this case, two types of load were considered because of the position of the shaft and the knives it carries. The loads are (a) Torsional load and (b) Transverse load. The torsional load on the shaft is due to power input source (the motor). Transverse load is as a result of the knives mounted on the shaft as illustrated in Figure 2.
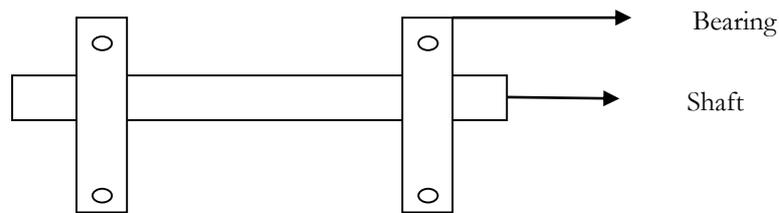
Figure 2: diagram representing transverse load as a result of knives mounted

(a) *Stresses on the Shaft:* The bending moment stress α x b:

$R \times b = \frac{M_B C}{I}$ (11)

Where M_B is the bending moment, I is the area moment of inertia, R is the diameter of the shaft, and C is the neutral axis = d/2.

$I = \frac{\pi d^4}{64}$ (12)

$A \times b = \frac{32 M_B}{\pi d^3}$

Tensional stress L_{xy} is deduced as:

$L_{xy} = \frac{Tr}{j}$ (13)

Where T is the torque, r is the radius, and j is the polar moment of inertia.

$$j = \frac{d^4}{32} \quad \text{and} \quad T_{xy} = \frac{16T}{d^3}$$

To determine the diameter of the shaft for the combined bending and torsional load:

$$\tau = (\alpha bx)^2 = (\tau_{xy})^{2^{1/3}}$$

$$\tau_{max} = \sqrt{\left(\frac{16\,M_B^2 + T^2}{d^3}\right)} \tag{14}$$

$$ds^3 = \frac{32n\,M_B^2 + T^2}{ay} \tag{15}$$

(b) *Motor Selection:* The capacity of the motor depends on the required energy per minute and the efficiency of the drive. For this design, elastic strain theory was employed for the determination of power and cutting force from the compressive, tensile and shearing stressed test and experimental data as follow:

Motor speed of engine   =   3600rpm
Power rating of engine   =   5.5hp (= 5.5 x 0.7457kW) = 4.101kW

(c) *Determination of the Cutting Force:* The force required to granulate a waste plastic product is a function of shear force deduced as:

$$F = F_s + F_a \tag{16}$$

Where, F_s is the shear force (N) and F_a is the acceleration force (N)

(d) *Transmission Belt Design:* The peripheral speed of a pulley moved by the belt is defined as $V_p = W_p/2$ and assuming that without slipping, $V_1 = V_2$ i.e., peripheral speed of the driving and driven pulley will be the same, thus the speed ratio of the belt driven will be inverse of the pulley diameter. In this paper a transmission belt was used to transfer the same rate of power coming from the engine to the granulator, the speed can be regulated from the motor.

(e) *Determination of Belt Tension:* For belt the tension T_1 and T_2 can be determined as follows:

$$\frac{T_1 - mV_1}{T_2 - mV_2} = e^{f\emptyset} \Big/ 1/2 \sin\theta \tag{17}$$

and

$$m = BTP \tag{18}$$

Where m is the mass of the belt per meter, B is the belt width in meters, T is the belt thickness in meters, P is the density of belt (1250kg/ms), $\emptyset$, θ is the groove angle for the V-belt and 180^0 for a flat belt, f is the coefficient of friction between belt and pulley and V is the belt velocity in m/s.

(f) *Critical Speed of Shaft:* The critical speed (NC) of the shaft is deduces as follows:

$$NC = \frac{(187.5)}{\sqrt{\delta s/1.27}}\,rpm \tag{19}$$

The deflection due to each weight is

$$S = \frac{5 \times WL^4}{385\,EI} \tag{20}$$

Where, L (= 0.4m) is the length of shaft, E (= 207 x 10^9 N/m²) is the modulus of elasticity, W (= 20.02 x 9.81 = 196.4N) is the weight of shaft, I is the second moment of inertia deduced as follows:

$$I = \frac{\pi d^4}{64} = \frac{\pi\,(0.02)^4}{64} = 7.854 \times 10^{-9}\text{gm}^4$$

For a cylindrical object or component

$$\delta s = \frac{5}{384} \times \frac{196.4 \times (0.4)^4}{207 \times 10^9 \times 7.854 \times 10^{-9}} = 4.027 \times 10^{-5} m \tag{21}$$

Substituting (21) into (19) gives:

$$NC = \frac{(187.5)}{\sqrt{4.027 \times 10^{-5}/1.27}}$$

$$NC = 33,297.55\,rpm = 3,487.4\,rad/sec$$

Speed of shaft (1440 rpm)

$$= \frac{2\pi \times 1440}{60} = 150.8\,\text{rad/sec}$$

Since the speed of the shaft, 150.8 rad/sec, is lower than the critical speed. i.e., 3,487.4rad/sec, there will be no displacement of mass from the axis of rotation.

2.5   Manufacturing Process

The various component will be manufactured using the following manufacturing process.

Machine Bed: The machine bed is made of 6mm angular bar steel constructed to give support and stand the machine. It is fabricated into a rectangular cage in which the entire machine system rests, attached to the machine bed are shock absorbing component to reduce shock and vibration

Service Engine (5.5hp): It is the mechanical component of the machine which is motor driven and regarded as the power house of the machine system. It is a prime mover of the shaft in which the cutting blade are attached which is a drive to initiate crushing and granulation.

Crushing Chamber: The crushing chamber simply houses the crushing shaft, which is the component that performs the granulation and crushing function in the machine with the aid of the cutting blades arranged around the shaft with regular spacing used for crushing and granulating respectively.

Shock Absorbing Coupler (Flexible Coupler): A coupler is a device used to connect two shafts together at their ends for the purpose of transmitting power or rotation. Coupling do not normally allow disconnection of shafts during operation, however there are torque from one shaft (i.e., engine) to another (i.e., crushing shaft with blades) where the two shafts are slightly misaligned. The coupler has a thickness of 3mm and a diameter of 13cm. Generally the primary purpose of coupling is to join the two rotating shafts (i.e., engine and crushing shaft), while permitting some degree of misalignment or end move, or both. The coupling also serves as vibration damper or noise reduction. It protects the driving and driven shaft member against harmful effects produced due to misalignment of the shaft, sudden shock, overloads, shaft expansion or vibration etc. This helps the machine to be mechanically flexible and transmitting the same power from the engine to granulator.

Hopper: It is used to feed the crushing chamber with plastic film materials. It is a sheet metal welded into a *V*-shape, with safety cover to prevent the escape or sudden jump of plastic film specimen that maybe injurious to an operator during crushing process.

Crushing Shaft: it is a cylinder made from stainless steel, arranged on its cross section are blades (rotating and fixed) arranged at an angle and distance for shearing and granulating of the plastic film material. Since the blades receive direct shock during the shearing action, they are ground to form tapered cutting edges so as to ensure better cutting efficiency. The blades are arranged in such a way that the tapered ends of the stationary and rotating blades are parallel to each other so as to ensure maximum shear action between them. More also the positioning of the blades are in such a way that there is controlled clearance between the rotational and stationary blades as well as clearance between the rotating blades and the screen net. The blades are spaced two inches from each other with a height of 3cm, length of 30cm and a thickness of 3 inches or 7 1/2cm.

Discharge Channel: it is made from sheet metal and is used to enhance passage of the crushed materials from the crushing chamber into the collection basin or bowl.

Screen Net: This is a net of 6mm hole used to ensure that the required sizes of granules or pallets are discharged from the crushing chamber.

Bearings: These are simply used to aid free rotations of the crushing shaft and are selected based on their load capacity and life expectancy with other necessary considerations (such as the nature of the relative motion required, the type of constrain applied and environmental conditions etc.)

V-Bolt and Nut: It is one of the materials joining process used during the machine fabrication, to fastening some of the machine parts inconvenient for welding during the assembly operations or stage.

2.6   Working Principle of Plastic Granulator

When the switch to the machine is put on, the engine motor shaft turns, thereby generating rotary motion on the flexible coupler and the same torque from the coupler is transmitted to the crushing shaft, which causes the rotary crushing blades attached to the shaft to rotate about the vertical axis of the crushing chamber, thereby generating the required power for shearing and granulation.

As the plastic film materials are fed through the hopper into the crushing chamber, the rotary blades which are already in motion granulate the material with the aid of the fixed blades and the walls of the crushing chamber. As the granulation process is taking place, the required size of the granules or pallets are forced out by the motion of the rotating blades via the 6mm holes on the screen net. These granules are then discharge into the collection basin through the discharge channel. Figure 3 shows different views of the designed plastic film granulating machine.
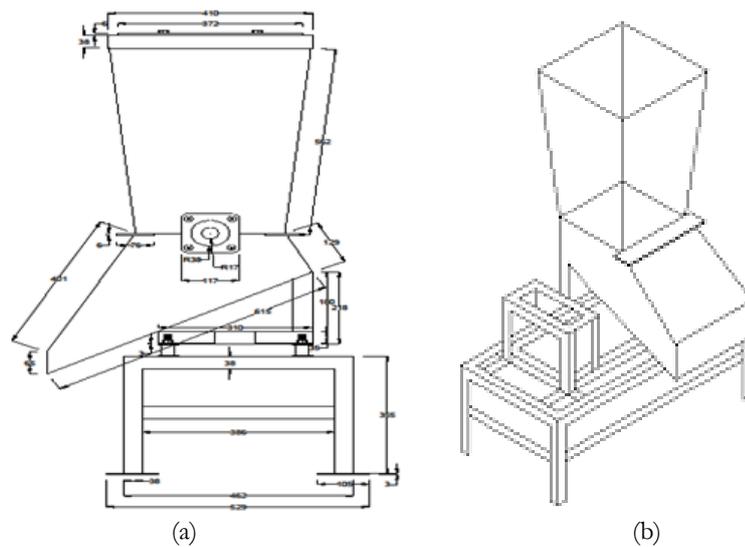
(a) (b)

Figure 3. Designed plastic film granulating machine (a) side view (b) isometric view

2.7 *Application of Grinded Plastics*

Plastics can be used to make petroleum since that is their parental source in an environment or vacuum. It can be converted back to fuel for diesel engines. It is a means of recycling to make household items like cups, buckets.

2.8 *Conversion of Granules to Petroleum*

The granulated plastics are from petroleum, and can also be converted back to petroleum. This is done after granulation, by putting them into a distiller (used to distil alcohol and even water) under an open flame, at a temperature of 5000^0C during the heating process the plastic granules decomposes from solid to liquid and thus, evaporates to condense into the condenser. At that temperature, the condensed gas is a petroleum product (i.e., diesel or kerosene), which runs on any diesel engine. It can also be used as furnace fuel. Although, may require blending to improve the Octane-rating.

3. Result

When the machine was test-run unloaded, it was observed to be in good working condition, and when the machine was loaded with plastic film materials, it was also observed to be in good and effective order. Then, the efficiency of the machine is evaluated based on the weight ratio of the input materials to the output materials (products). Figure 4 shows the pictorial view of the fabricated plastic film granulating machine.

(a) (b)

Figure 4. Pictorial views of the fabricated plastic film granulating machine (a) front (b) side.

The test results are as follows:

Weight of plastic film materials before operation = 5kg

Weight of granules = 3.75kg

$$Machine\ efficiency = \frac{Total\ output\ weight}{Total\ output\ weight} \times 100$$

$$= \frac{Weight\ of\ granules\ produced}{Weight\ of\ plastic\ film\ materials\ before\ operation} \times 100$$

$$= \frac{3.75}{5} \times 100 = 75\%$$

Therefore, machine efficiency = 75%.

4.   Conclusion

As stated earlier, the design and fabrication of a plastic film granulating machine is convinced by the researchers to drastically reduce the environmental and health problems caused by plastic film wasted in modern day society, as well as to ensure the conservation of plastic film waste. With the successful design and fabrication of this machine using locally sourced materials, these aims have been realised. Therefore, if this machine is effectively and judiciously put into use, the economy of our country will experience a strong boost due to the fact that it will create job and employment opportunities to many people especially, the potential entrepreneurs.

The machine can be used in slicing various sizes waste polymer in most process industries even for domestic purpose. We therefore recommend that for mass granulating the number of knives on the shaft should be increased as this will equally increase the life span of the bearing since they are supporting the weight of the shaft with knives (blades on it). The completion of this project has shown the industrial sector in the country to encourage the production of plastic granulating machine on a large scale, since it can be produced locally and therefore saving foreign exchange.

Conflict of Interests

The author declares that there is no conflict of interests regarding the publication of this paper.

References

Ghebre-Sellasie, I., Plains, M., Mollan, M. J., Pathak, N., Lodaya, M., & Fessehaie, M. (2002). Continuous Production of Pharmaceutical Granulation. US Patent 6,499, 984 B1.

Henson, F. (1998). *Plastic Extrusion Technology*. Macmillan Publishing New York. Hopkins Uni. Press, London.

John Jordan Reduction Solution (2015). Plastic Recycling Conference 2015.

Keleb, E. I., Vermeire, A., Vervaet, C., & Remon, J. P. (2002). Continuous Twin Screw Extrusion for the Wet Granulation of Lactose. *International Journal of Pharmaceuticals*, 239, 69 - 80.

Khurmi, R. S. & Gupta, J.K. (2007). Machine Design. Eurasia Pub House, Ram, Ragar, New Management. Deke, New York.

McRandle, P. W. (2004). Plastic Bottles. National Geography Press, New York.

Milgrom, J. (1982). Journal Polymer Plastic Technology and Engineering. Macmillan New York.

Schroeder, R., & Steffens, K. J. (2002). A New System for Continuous Wet Granulation. *Pharmaceuticals Industry,* 64, 283 - 288.

Selkirk, A. B., & Ganderton, D. (1970). The Influence of Wet and Dry Granulation Methods on Pore Structure of Lactose Tablets. *Journal of Pharmaceutical Pharmacology*, 22, 86 - 94.

Vecoplan, (2014). Paper and Plastic Recycling Paper and Plastic Recycling Conference.

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